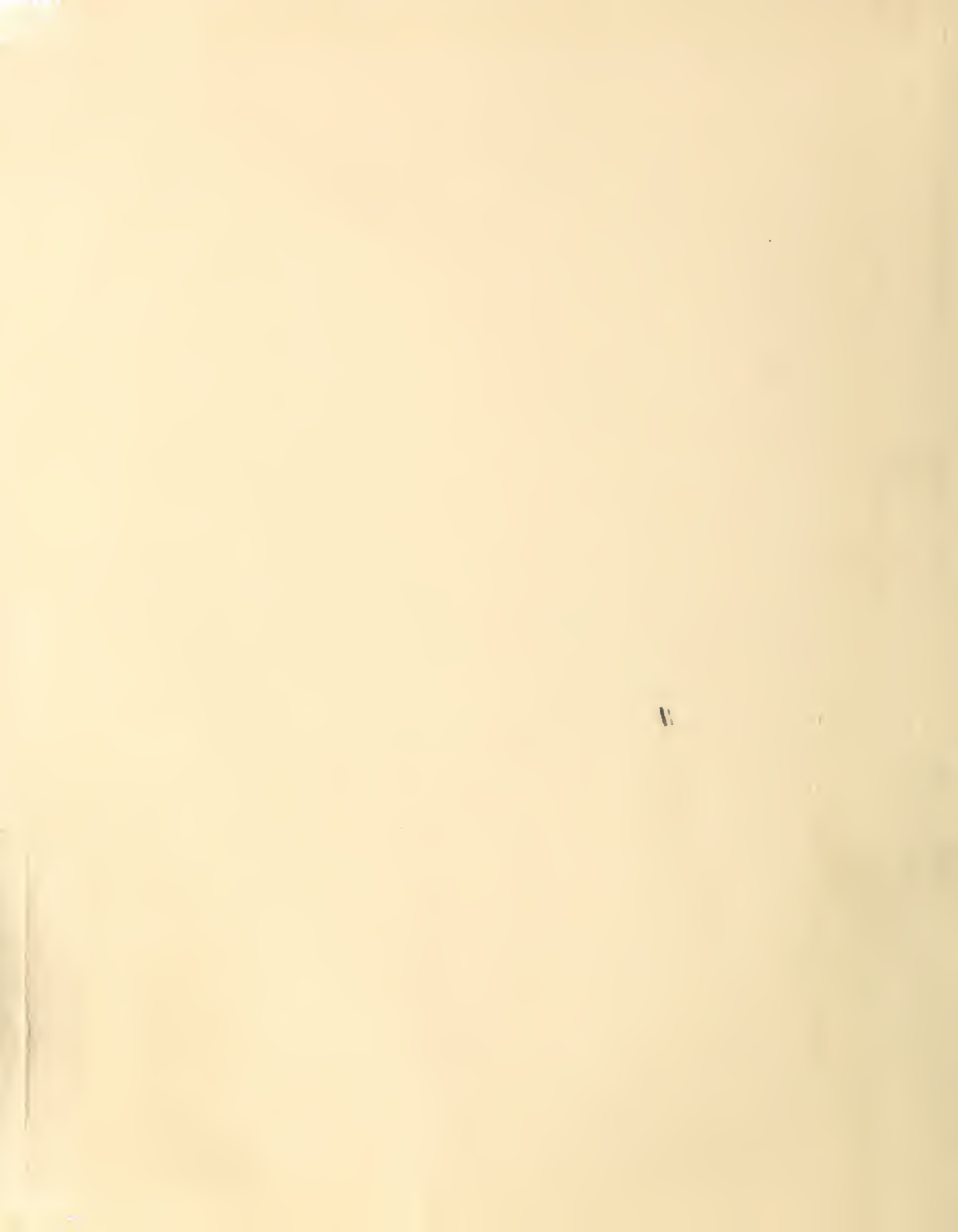


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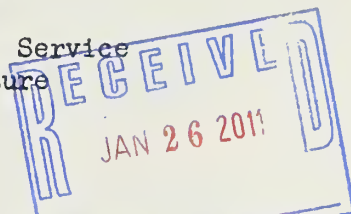
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WOOD FUEL COMBUSTION PRACTICE

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Although wood has been used as fuel since before the dawn of history, rapid advances in wood-burning equipment and methods have been made in the last few decades. These improvements are based upon a better fundamental knowledge of how wood burns, together with modern demands for better, more uniform heat, greater convenience, and lower costs of operation. Strides have been particularly notable in the design of industrial furnaces for wood waste, especially in areas such as the Pacific Northwest, where large supplies of waste offer a cheap fuel and competing fuels are comparatively expensive. This report is intended primarily for combustion engineers, designers of fuel equipment, and other technicians interested in the use of wood waste as fuel. The forms of wood waste available as fuel and methods of preparing and handling them are discussed in another Forest Products Laboratory report.²

Adequacy of Wood Fuels

The many uses of wood fuel are ample evidence that it is adequate as a source of heat energy. In the Pacific Northwest, wood fuel produced 175 billion kilowatt hours of electric power in 1924 at an average rate of 635 kilowatt-hours per unit (200 cubic feet) of Douglas-fir waste. In 1941 the output per unit of waste (48 percent moisture content) at the municipal steam plant of Eugene, Oregon, was 975 kilowatt hours, and modern plants may be expected to produce regularly upwards of 800 kilowatt hours per unit. A Portland, Oregon, public-utility power plant has been operated with wood for many years. Unquestionably, waste wood can fill many fuel needs if suitable equipment and economical operating practices are provided.

Wood waste may not be a deluxe fuel -- except in the form of alcohol or briquets -- but its irregularity, bulk, and varying moisture content are offset in many instances by its renewability, availability, and low cost. It can be hogged or chipped to relatively uniform size for better handling and better fuel-bed conditions. In manufacturing plants utilizing their refuse for fuel, synchronization of production and consumption is a real advantage not lessened by the bulkiness of the fuel. Where extensive shipping and storage are involved, bulk is objectionable. No special storage tanks are required, however, as for oil, and in outdoor storage there is no risk

¹Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

²Reineke, L. H. Wood Fuel Preparation, Forest Products Laboratory Report No. R1666-19, 1947.

of the spontaneous combustion that often occurs with coal. Wood has a lower heat-producing content per pound than coals and oils, which increases its bulk per unit of heat content as tabulated below:

<u>Fuel</u>	<u>Cu. ft. per million B.t.u.</u>
<u>1</u> Aspen	7.0
<u>1</u> Hickory	3.7
Coke	2.6
Anthracite	1.3
Fuel Oil	0.9

1At 8,600 B.t.u. per pound dry weight.

The moisture content of wood, if high, will increase these ratios somewhat on the basis of available heat.

Usable Heat Content of Wood

The total heat content of a pound of oven-dry wood is approximately 8,600 British thermal units for hardwood species and slightly higher (9,150) for the resinous conifers. Any moisture in the fuel will not reduce the total heat produced, but its presence in the flue gases, together with the water formed in burning the hydrogen in the fuel, reduces the recoverable heat by carrying heat up the stack. Flue-gas temperatures are usually 400° F.; therefore, any water present in the flue gases is in the form of steam. Since the vaporization of water to steam requires about 1,000 B.t.u. per pound and additional heat is required to raise the water from room temperature, say 65° F., to 212° F. and to raise the steam from 212° F. to a flue temperature of 400° F. or higher, each pound of steam carries with it up the flue 1,210 B.t.u. Since wood is never completely dry, allowance must be made for heat loss due to this (free²) moisture. Approximately 0.55 pound of water is formed in burning the hydrogen in 1 pound of dry wood, so that 660 B.t.u. are lost from this source. This gives 8,600 minus 660, or 7,940 B.t.u. An additional 690 B.t.u. are lost up the stack in other hot flue gases (carbon dioxide, nitrogen, excess oxygen), leaving 7,250 B.t.u. as the net usable heat from 1 pound of dry wood.

Green wood is not efficiently burned in ordinary stoves. It will hardly burn at all in some types, and will cause creosoting and condensation troubles at low rates of combustion in others. The large amount of potential heat in the volatile gases is lost when the temperature in the fire box is below 1,100° F., the ignition temperature of these gases.

²"Free" moisture designates water absorbed by the wood, not chemically bonded or produced by the burning of the hydrogen in the wood.

In furnaces properly designed for burning wet fuels and operated at rates that maintain the necessary minimum ignition temperature, the volatile gases are burned and thermal efficiency is not greatly reduced by free moisture in the wood. For example, assume that the net heating value of 1 pound of dry wood is 7,250 B.t.u., and stack loss is about 1,210 B.t.u. per pound of free moisture, and the moisture content of the wood is 20 percent. The moisture in the wood (0.20 pound of water per pound of dry wood) entails a stack loss of $0.20 \times 1,210 = 242$ B.t.u., or 3.3 percent of the net heat content of bone-dry wood. If the wood has a moisture content of 60 percent of its dry weight, the resulting stack loss will be $0.60 \times 1,210 = 726$ B.t.u. per pound of dry wood, or 10.0 percent of the net heat content.

The difference in heat loss from green and air-dry wood thus amounts to only 6.7 percent. This raises some question as to the economic desirability of going to the expense of drying the wood before burning it where hopper or mechanical feed is used or where sustained fires are the rule and boiler capacity is adequate without maximum forcing. The costs of predrying, where waste heat can be utilized, can sometimes be recovered in large installations operating at full capacity through increased steaming capacity due to preheating and to reduced stack losses due to moisture in wet wood. The power required to put the wood through the dryer, however, reduces the net gain in heat. On the other hand, if fires must be started frequently or if the combustion space will be cooled unduly by charging the firebox with large quantities of green wood at rather long intervals, as in home furnaces, the added expense of drying may be justified for firing convenience.

Moisture contentUsable heat per unit volume¹Percent of
oven-dry weightPercent of usable heat based on wood
at 20% moisture content

0	103.4
4	102.7
10	101.6
15	100.8
20	100.0
30	98.2
40	96.5
50	94.8
60	93.1
80	89.7
100	85.0

¹Based on hardwoods with a gross heat value of 8,600 B.t.u. and net of 7,250 B.t.u. per pound of dry wood. The differences would be slightly less for conifers.

Efficiency of Wood Fuels

When wood burns, its hydrogen combines with oxygen to form water. For this reason wood, which is a little higher in hydrogen content and much higher in oxygen content than coal, has about 3 percent less of its total heat available than does coal and oil. Charcoal, alcohol, and lignin have a better ratio of total heat to available heat than does wood.

To recover as much heat as possible from wood fuels, specially designed or modified equipment operated by methods adapted to the fuel should be used. Coal-burning equipment and methods, for instance, will not give maximum heat recovery from wood. Motor fuels of alcohol derived from wood or of wood gas must be modified to match the performance or combustion characteristics of gasoline, or else suitable carburetor adjustments must be made for the alcohol or wood gas. The fuel used should be in the form best adapted to the equipment. Chunk wood, for example, burns with lower efficiency in ordinary fireboxes where gaps and voids in the fuel bed make for irregular burning, but in the magazine-type slow-combustion stoves, chunk wood is entirely satisfactory except in cases of extreme irregularity of form.

Principles of Combustion of Wood Fuels

Three distinct phases of the process of combustion can be recognized, which may be proceeding in sequence or simultaneously. In phase 1, free water is removed by evaporation (through air flow) at temperatures below the boiling point of water or by vaporization at temperatures above the boiling

point, with vaporization accounting for the major drying effect in ordinary burners. In phase 2, the chemical breakdown of the wood into charcoal, gas, and volatile liquids takes place, carbon dioxide and water being the chief end products. In phase 3, the charcoal burns, forming carbon dioxide either directly or with an intermediate conversion to carbon monoxide.

Phase 1 may be accomplished in part outside of the burner by using flue gases or heated air to preheat the wood and drive off some of the free water. If finely divided wood is overheated, however, some of the combustible volatiles may be lost. For this reason it is preferable to preheat the air supplied to the fire instead of preheating the fuel. Removal of water can then be completed within the burner, either by direct contact of the wood with flames or burned gases, or by radiation from flames, hot coals, or the interior burner surfaces. The radiant heat is the more effective because it is more rapidly absorbed.

Phase 2 also requires heat to remove the gases and volatile liquids from wood. Part of the heat required is supplied by the exothermic (heat-producing) reaction of the light wood tar first produced as it breaks down into gas, ordinary tar, and carbon; the rest must be supplied as in phase 1, by wood more completely burned. Burning of the volatilized combustibles produced in phase 2 supplies heat usable in phases 1 and 2 and for application to the development of steam. In phase 3, the burning charcoal sustains its required temperature, after the initial kindling, by conduction inward from the burning surface of the fuel and by radiation from adjoining pieces of burning fuel. It is in this phase that the combustion cycle is chiefly maintained and useful heat furnished.

The combustion of fuel requires the presence of oxygen, which is supplied by the air admitted to the burner. Twenty-one percent of the air (by volume) is oxygen; the rest is chiefly nitrogen, which does not burn. As air passes through a bed of glowing fuel its oxygen combines with the carbon to form carbon dioxide. A 2-inch layer of incandescent carbon usually suffices to consume all the oxygen in the air, under normal draft. A thicker layer of glowing carbon will add another atom of carbon to the carbon dioxide, converting it to carbon monoxide. This carbon monoxide is added to the volatile combustibles distilled from the fuel in phase 2, and additional air for complete combustion of all gases must be introduced above the fuel bed. Since the ignition temperature of these gases is approximately 1,100° F. or higher, the over-fire air should be preheated to insure ignition and be introduced in such a manner that it will be thoroughly mixed with the gases.

The large amount of volatile matter, comprising 60 percent of the weight of the oven-dry wood, absorbs 200 B.t.u. per pound for distillation, and this absorption, together with the heat absorbed in vaporizing the water at 1,000 B.t.u. per pound, may cool the gases below ignition temperature when fresh fuel is added. For this reason, automatic stoking is more efficient than hand feeding. Not only does incomplete combustion of the gases constitute a big loss in efficiency; pyroligneous acid, and tarry substances in the unburned gases cause troublesome corrosion and staining around stove-pipe joints.

For complete combustion of gases, about 80 percent of the air needed should be supplied over and around the fuel. Theoretically, about 6 pounds of air are required to burn 1 pound of dry wood completely, but because of incomplete mixing with the gases an excess of air must be used. Too great an excess of air, however, reduces efficiency because heat is lost in raising the temperature of the excess air to flue temperature. Proper air control to maintain the carbon dioxide in the flue gas at 15 percent will give the minimum loss (4 percent) due to excess air.⁴ This loss will increase to 6 percent if variation in the air supply reduces the carbon dioxide content to 11-1/2 percent or increases it to 17 percent.

The high percentage of volatile matter in wood produces a long flame, necessitating a larger combustion space above the fuel bed than is required for coal. Thorough mixing of air with the gases becomes more difficult as this space increases. Therefore, careful design for the introduction of over-fire air is necessary. Over-fire air jets, steam- or blower-operated, help to reduce smoke and improve the combustion of soft coal.² Such jets might also be effective in wood-burning furnaces.

Improved Equipment and Operation

Some advances in wood-burning equipment and methods have been made in the last few decades. Mechanical feeds and automatic controls have been applied to wood-burning furnaces, and special domestic burners for sawdust and hogged fuels have been developed. Suspension burning of dry wood has been applied in industrial furnaces. A special type of furnace has been developed for burning very wet wood and bark, and high-efficiency magazine-type heaters of the slow-combustion type have come into use. Fireplaces have been redesigned to incorporate air chambers for circulation and heating of room air, and even charcoal grills are equipped with reflector-oven housings.

Industrial Wood-fuel Equipment

Fair efficiency has been developed in charcoal-burning gasogens for motor vehicles and wood-burning gas producers for operating generators or providing process gas in remote, undeveloped territory. A wood-using gas producer has been used for firing a rotary rock kiln.⁶ Gas made in one stationary producer using chunk wood contained about 55 percent of the total fuel energy of the wood, and the over-all recovery in the form of electricity was about 10-1/2 percent of the total energy, which was considerably more than the 4 percent return from the steam-generator plant it replaced. The producer-gas principle has been applied to some industrial furnaces.

⁴Simmons, R. E. "What CO₂ Is Best?" Power, Vol. 85, p. 571, Aug. 1941.

²"Application of Overfire Jets to Prevent Smoke in Stationary Plants," Tech. Rept. No. 7, Bituminous Coal Research, Inc., Pittsburgh, Pa.

⁶Azbe, V. J. Rock Prod. 45, p. 60, June 1942.

The three-phase combustion sequence has been used in the Hoff⁷ design of furnaces for burning green wood and wet bark in the newer steam-generating plants. In this type of furnace, green fuel is fed to the top of a drying plate set at 60° from the horizontal for phase 1 combustion. It progresses downward to a second plate, a distillation section set with slightly less slope, for phase 2 burning, and thence to a step-type grate set at 45°, on which phase 3, combustion of the carbon, takes place. A firebrick arch located above the fuel bed radiates heat produced by combustion of the carbon and gases to dry incoming green fuel and drive off the combustible volatiles. These volatiles, mixed with carbon monoxide formed in burning the carbon, pass over a bridge wall in which tuyeres are placed to supply heated air for complete combustion of the gases. This system, combined with more efficient boilers, high steam pressures, and improved prime movers, yields an over-all efficiency in electrical-power generation of about 14 percent of the energy contained in the wood, partly due to the uniform fuel bed and accurate control resulting from the use of hogged fuel. Fuel hoppers and automatic feeding units are essential parts of an efficient installation and are necessary to maintain uniformity of conditions desired.

Where the use of coal is necessary at some seasons due to shortage of wood fuel, the wood-burning unit is best cut into the side or back of the boiler to permit operation with either wood or coal without interference. Some furnaces have been designed to use oil as an alternate fuel, and some to use both coal and oil as alternates. In combination furnaces of this nature, a boiler efficiency of 60 percent is attained. Their steaming capacity with coal is about 1.4 times that with wet bark and refuse.

Where finely divided wood fuel has a moisture content consistently under 60 percent, it becomes possible to burn it in suspension, and this method is especially advantageous when the fuel is derived from dry wood, as at planing mills and furniture factories. In suspension burning, the incoming fuel drops through the hot gases and is progressively dried, distilled, and burned. The larger particles fall to the base of the furnace where they maintain a hot radiating surface. No grates are required, less space is used, and higher burning rates can be maintained. Change-over to suspension burning of pulverized coal is swift and simple.

The burning of small, solid wood pieces, such as edgings and board ends, in industrial furnaces causes trouble in hoppers and in feed mechanisms due to arching and jamming unless it is in hogged form. Veneer scrap, especially, needs to be hogged before firing, since the unhogged material is so bulky, stringy, and difficult to handle that firebox doors are open almost continuously and fuel beds are not compact. The waste bark at veneer plants does not improve the fire bed and is usually quite wet, especially where logs are heated before peeling. Some solid scrap, such as veneer cores, is necessary to provide a sustaining bed of hot coals. Where cores can be utilized for crating or other purposes, coal is sometimes used for the sustaining fire, but combustion is erratic and furnace efficiency low.

⁷Made by M. A. Hofft Co., Indianapolis, Ind.

Sander-dust Burners

The burning of sander dust that cannot be disposed of for wood flour or other use entails the risk of explosion under certain conditions. Any combustible dust will burn with explosive force when the concentration of dust particles in the air is such that particles are surrounded by sufficient air for combustion to raise all particles to the ignition temperature and spaced closely enough to permit propagation of flame from one particle to the next. Greater or lesser concentrations not meeting these conditions are not explosive.

Explosion hazards can be eliminated in closed pneumatic systems by using any inert atmosphere (nitrogen, carbon dioxide, flue gas) in which the oxygen content is relatively low (under 12 percent). Such a practice is not, however, usable in pneumatic dust-collecting and transport systems, and there will be risk of explosion if the dust is blown directly into the furnace. If, however, the fine sander dust can be diluted by mixing with coarser material such as sawdust and shavings, explosion risks will be eliminated if the fuel is fed to the fire through a hopper or other means which does not separate the dust from the mixture. Another alternative is the concentrating of the dust, in suspension, to a density above the explodable concentration before introducing it into the furnace. A recent installation in Wisconsin accumulates sander dust in a separate cyclone where it is stored in suspension. An electronic "eye" measures the dust concentration and when the desired concentration is reached it actuates a valve permitting the dust to pass to a special dust burner opening into the combustion chamber of the main furnace. As the fuel is used up, the concentration of dust diminishes and the electronic control cuts off the supply to the burners when the concentration drops to a value somewhat above the explodable concentration.

Hogged Fuel and Sawdust Burners

In the Pacific Northwest, where hogged fuel is plentiful and cheap, many sawdust or hogged-fuel burners have been installed for both domestic and industrial purposes. A few are in use in New England.

This type of burner consists of a hopper from which the fuel feeds by gravity onto an inclined plate in the front of a combustion chamber. This chamber is lined with a refractory material and is large enough, in most designs, for complete combustion. Secondary air is introduced above or around the fuel. Heat radiation from the refractory lining maintains the temperature of the volatiles at the desired minimum of 1,100° F. and provides the heat for the drying and distillation phases of combustion.

In large installations, some type of automatic stoking usually is used. For home-heating furnaces, the sawdust burner is installed by removing the furnace grates and ashpit door and sealing the unit into this opening. The care of these burners and their rating are covered in detail in a bulletin published by Oregon State College.⁸

⁸-Willey, E. C. Rating and Care of Domestic Sawdust Burners, Bull. 15, Eng. Exp. Station, Oregon State College, Corvallis.

Several types of home-made wood burners have been developed for household furnaces.² These operate with sawdust, shavings, and hogged fuel, as well as with solid wood, and can be built fairly easily.

Chunk-wood Burners

Solid wood, either round, split, or as slabs or lumber scrap, can be burned in almost any furnace or stove equipped with grates fine enough to retain wood ash, but efficiency will be low if the combustion space is small. The conversion units previously mentioned provide additional burning space. On large furnaces designed for coal, a "Dutch oven," which is a refractory extension of the firebox, is installed for this purpose.

The burning of chunk wood in large furnaces is not very efficient because of irregular draft due to the frequent opening of furnace doors for recharging and because of the difficulty of establishing and maintaining a uniform fuel bed. Some attempts have been made to feed charges of 4-foot and 8-foot round wood, crosswise of the grates of large furnaces, through draftless doors extending the full width of the firebox, but jackstrawing and the irregular form of the sticks created excessive voids that reduced combustion efficiency.

In household furnaces and stoves, the use of short lengths of wood and deep firepots permits close packing of the sticks, which gives better operation. These burners, however, are not operated at uniform rates, as are industrial furnaces, but at rates that vary widely according to the weather, cooking needs, and the like. Under such conditions it is sometimes difficult to maintain the temperature in the combustion space at the ignition temperature. As a result, the volatiles go up the chimney unburned, creating smoke and corroding metal stovepipes. If the stovepipe is long, there is strong likelihood that the flue gas will be cooled to the point where the tar, and sometimes water, will condense and leak through the joints, or a rapid rise in the flue-gas temperature may cause chimney fires by igniting the accumulated tar. The obvious correction is to use the shortest possible pipe between stove and chimney. Short pipes, however, afford less heating surface and, in burners designed for coal, combustion space is reduced, with the result that the long flames produced by wood at high operating rates will extend into the chimney, causing considerable loss of heat. To avoid chilling the combustion space at low operating rates, charges of fresh fuel should be small and preferably dry. After the initial charge has burned enough to lose its volatiles, new fuel should be added frequently, but only in small amounts.

The burning of wood in fireplaces is the least efficient method of generating heat. Fireplaces, however, may consume less fuel than a furnace in dispelling morning and evening chill in spring and fall because of the short duration of the fire. Ordinary fireplaces deliver to the room only a

²Hicock, H. W., Olson, A. R., and Seely, L. E. "A Wood-burning Conversion Unit for Household Furnaces," Bull. 463, Connecticut Ag. Exp. Station, New Haven.

tenth of the heating value of the wood; the rest is lost in heating the great excess of air passing out of the room through the chimney. A chimney damper, closed down as much as possible, will reduce the amount of air drawn from the room. A duct supplying air to the fire from outside the building will similarly conserve the warmed air in the room.

The modern heating-type fireplace¹⁰ has metal side walls and back, with space for air to circulate between the walls and the fireplace setting. It provides inlets near the floor level and outlets near the mantel to circulate room air around the fireplace shell, and provides convection air heating in addition to radiant heating. Ashes should be kept to the tops of the andirons to prevent rapid burning out of the fuel and to accumulate a bed of glowing embers to provide maximum radiation and ignite fresh fuel. The fire can be checked by sprinkling lightly with ashes, and a fire thus banked will hold for 10 hours or more. Fires in Franklin stoves or their modernized form of combined stove and fireplace¹¹ can be managed similarly.

Improved stoves of the slow-combustion type have been used in Europe for some time. A few were imported in the late thirties. Several American designs¹² now utilize the basic principles of the European stove. Essentially, this type of wood burner consists of a relatively gastight fuel magazine, fed from the top and with a grate at the bottom. Primary air is admitted at the bottom of a shell surrounding the magazine, the space between shell and magazine wall forming a secondary combustion chamber in which the gases driven from the wood in the magazine are burned. Air ducts in the secondary chamber provide the air required for complete combustion of gases, and draft can be closely controlled. The gases distilled from the charge must pass down through the bed of coals, by which they are heated to the required temperature for subsequent complete combustion, before going into the secondary chamber. In effect, this design constitutes an underfeed type of stoker in inverted position. The magazine holds sufficient wood for a period of 8 hours or more, depending on the severity of the weather, and the charge may last as long as 30 hours under very mild conditions.

Wood for these magazine-type burners must be cut somewhat shorter than the magazine, so that the fuel charge will not jam as it moves downward. Sticks should be packed closely and evenly, with sufficient dry kindling to insure a good start. Recharging should be deferred until all gases have been driven off and the magazine is smoke-free; otherwise the smoke in the magazine will escape into the room and gas may backflash if the stove is very hot. Such backflashes are, however, rare and can be avoided by proper choice of refueling time.

¹⁰Manufacturers of such fireplace installations include Bennett Fireplace Corp., Norwich, N. Y.; Denley Bros. Co., 13900 Miles Ave., Cleveland, Ohio; Gabriel Fireplace Unit, Cleveland, Ohio; Hearthaire Co., 3126 Scarborough Rd., Cleveland, Ohio; Heatilator, Inc., 100 E. Brighton Ave., Syracuse, N. Y.; Majestic Co., Brown St., Huntington, Ind.; and Superior Fireplace Co., Los Angeles, Calif.

¹¹Manufactured by Edwards Mfg. Co., 529-49 Eggleston Ave., Cincinnati 2, Ohio; and Portland Stove Foundry Co., Portland, Maine.

¹²Manufactured by Automatic Draft and Stove Co., Lynchburg, Va.; Riteway Products Co., Harrisonburg, Va.; Shapleigh Hardware Co., 900 Spruce St., St. Louis, Mo.; and Shenandoah Equipment Corp., Harrisonburg, Va.

Prospects for Further Improvements in Use of Wood Fuels

Intensive research sponsored by the hard and soft coal and oil industries has resulted in notable improvements in operation and styling of units burning these various fuels. No similar concerted study backed by the wood industries has been carried out. Progress in improving industrial wood fuel use has been good, but improvements in domestic applications, while substantial, have been insufficient to maintain the competitive position of domestic wood fuel in competition with other fuels utilizing well-styled equipment.

Possible improvements are not limited to design and operation of the equipment for wood burning. Opportunities are excellent for better channeling of forest and mill wastes into fuel use, for improvements in handling the material, for better distribution to consumers, and for more aggressive selling of wood fuel.

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